Renewable and Sustainable Energy Reviews 29 (2014) 336–344

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Global estimates of energy consumption and greenhouse gas emissions

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ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form
13 August 2013
Accepted 24 August 2013
Available online 20 September 2013

Keywords:
Energy consumption
Economic growth
Greenhouse gases
Cointegration
Global regions

ABSTRACT

The present study examines the long-run relationship between energy consumption and greenhouse gas emission for different groups of countries comprising lower middle income, upper middle income, and heavily indebted countries, East Asia and Pacific, East Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, South Asia, Sub-Saharan Africa and for aggregate data of the world. The data has been analyzed by using various econometric techniques, specifically the Johnson cointegration, modified version of Granger causality and variance decomposition analysis from the period of 1975 to 2011. The results confirm that there is a long-run relationship between greenhouse gas emissions (i.e. agricultural methane emission, agricultural nitrous oxide emission and carbon dioxide emission) and energy consumption. The results of Granger causality indicate that energy consumption Granger causes greenhouse gas emission but not vice versa. The important finding is that energy consumption Granger causes GDP per unit energy use, which confirms the energy led growth hypothesis in the world. However, the vice versa relationship does not hold. The results imply that a policy to cut energy consumption tends to diminish greenhouse gas emission though affecting GDP of countries negatively.

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1. Introduction

Efficient consumption of energy is widely viewed as a rather inexpensive way to cut total energy consumption and thus greenhouse gas emissions. Many agencies at national and international levels recommend energy efficiency measures. These measures in fact act as a way to reduce significant amounts of greenhouse gas emissions without incurring real cost and promise potential net benefits ([25]). The continued growth of global emissions and their possible adverse effects on global warming have shifted focus to relative contribution in total emissions and size of relative efforts undertaken by countries to mitigate these emissions [37].

Most of the greenhouse gas emissions that emanate from the residential and the commercial sectors are a direct result of energy use inbuildings. GHG emissions take place through direct emissions from the on-site combustion of fuels for heating and cooking, and emissions from the use of electricity for heating, cooling and providing power to

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.08.091

Table 1
Average electricity generation (terawatt-hours).

Terawatt-hours	1970s	1980s	1990s	2000s	2010	2011	Change 2011 over 2010 (%)	2011 share of total (%)
North America	2414.6	3018.3	3912.6	5012.3	5183.7	5204.5	0.4	23.6
South and Central America	6242.6	7017.3	8912.0	1023.9	1102.5	1145.6	3.9	5.2
Europe and Eurasia	3012.5	3721.9	4432.0	5171.9	5323.2	5278.6	−0.8	24.0
Middle East	6684.8	7342.9	8124.9	8848.0	871.4	912.1	4.7	4.1
Africa	464	512.3	588.3	639.8	659.3	657.1	−0.3	3.0
Asia Pacific	5124.3	6916.3	7825.3	8412.3	8225.7	8820.1	7.2	40.1
Total world	23942.8	28529.0	33795.1	29108.2	21365.8	22018.1	3.1	100.0

Source: Ref. [4].

Table 2
Regional energy use (kWh/capita).

kWh/capita	1970s	1980s	1990s	2000s
USA	91214	90124	89021	87265
EU-27	37214	39912	40240	40825
Middle East	812	11214	19422	34784
China	1216	4412	8839	18618
Latin America	7234	9121	11281	14428
Africa	5412	6124	7094	7792
India	1723	2568	4419	6280
Others	28652	26124	25217	24814

Source: Ref. [23].

buildings. Emission reductions from buildings can be achieved by controlling emissions from the energy supply or by decreasing energy consumption through improved building design, increased energy efficiency and conservation, and using other mechanisms which reduce energy demand in buildings [5].

The International Energy Agency [21] and the Intergovernmental Panel on Climate Change [24] have calculated that use of energy efficiency measures drives out the greatest portion of emission reductions and stabilizes the global climate. The renewed interest in the use of energy efficiency measures or mitigation assessment of greenhouse gases may also be attributed to the relationship between environmental pollutants, energy consumption and economic growth ([19] p. 358).

Table 1 shows the global trends of average electricity generation over the last four decades. The production of energy has resulted in global warming and poses a serious threat to the environment. To resolve the potential danger to climate by emissions from energy production, the Kyoto Protocol of the United Nations has been signed by a number of nations. This agreement aims at reducing harmful impacts of energy emissions on the climate. However, the dangerous concentration of energy production is playing havoc with the environment and hence has raised concerns. A global temperature rise of 2 °C is considered quite a high risk. Nevertheless, limiting this global temperature rise to 2 °C demands a 75% decline in carbon emissions in industrial countries by 2050. If the population reaches 10 billion in 2050, across 40 years, this averages to a 2% decrease every year. In 2011, the warming emissions of energy production continued rising regardless of the consensus on the basic problem. Table 2 shows the global estimates of energy consumption over the last four decades.

According to the Worldwatch institute [39] report carbon dioxide (77%), nitrous oxide (8%), and methane (14%) are the three main greenhouse gases that trap infrared radiation and contribute mainly to climate change. In order to prevent collapse, human civilization must stop increasing emissions within a decade regardless of the economy or population. Table 3 shows the global estimates of carbon dioxide emissions in different regions of the world.

In literature, there is sufficient evidence that increasing concentrations of atmospheric greenhouse gases from energy-related activities are responsible for changing the planet's climate. Other than the principal anthropogenic greenhouse gas, which is carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are also energy related greenhouse gases. An energy source's impact on the climate can be expressed in terms of its greenhouse gas emissions factor, which is, in this case, the volume of greenhouse gases emitted per unit of energy consumed [20].

There are a number of environmental problems that we face today. These problems range from continuously growing variety of pollutants and hazards, to ecosystem degradation over wider areas. In addition to this, acid precipitation, stratospheric ozone depletion, and global climate change are also noticeable. Of all potential climate threats, the most important environmental problem relates to the result of energy utilization which is the greenhouse effect. Unprecedented increase in atmospheric concentrations of greenhouse gases is expected to trap heat radiated from the Earth's surface, resulting in the rise of the surface temperature of the Earth and consequently rising sea levels [13].

The broad objective of this study is to empirically investigate the impact of energy consumption on greenhouse gas emissions in different regions of the world. The more specific objectives are

(i) To estimate whether there is a long-run relationship among greenhouse gas emissions, GDP per unit use of energy and energy consumption.
(iI) To explore the influencing directions between greenhouse gas emissions and energy consumption.
(iii) To compare the influencing magnitude of greenhouse gases on energy consumption in different group of countries.

The framework of the study is organized in the following manner. An introduction has been discussed in Section 1. Section 2 presents literature review. Data source and methodology are discussed in Section 3. Results are shown in Section 4. The final section concludes the study.

2. Literature review

The debate on climate change has brought focus to the problem of greenhouse gases emissions into the atmosphere. One of the most important issues in the policy debate is the role to be played by developing countries for reducing GHG emissions, and particularly CO_2 emissions side by side with developed countries. This debate demands reviewing the relationship among energy

Table 3
Average carbon dioxide emission in Million tonnes.

Regions	1970s	1980s	1990s	2000s	2010	**2011**	Change 2011 over 2010 (%)	2011 share of total (%)
North America	4437.2	5321.9	6012.8	6848.9	7191.2	7101.2	–	–
South and Central America	9241.2	1042.6	1101.8	1201.6	1291.6	1332.0	–	–
Europe and Eurasia	5014.2	5587.0	6325.2	7042.3	7063.2	7061.4	–	20.7
Middle East	1180.2	1309.2	1602.3	1891.0	1949.0	2025.0	3.9	6.0
Africa	4241.2	6394.2	8864.3	1042.0	1107.4	1113.3	0.5	3.3
Asia Pacific	7612.2	9928.3	11241.3	13942.0	14438.2	15399.9	6.7	45.3
Total world	31726.2	29583.2	35147.7	31967.8	33040.6	34032.7	3.0	100.0

Source: Ref. [4].

consumption, CO_2 emissions and economic development [16]. According to Cole et al. [9] (p. 221).

> The emissions of carbon dioxide, methane and nitrous oxide from agriculture together account for approximately one-fifth of the annual increase in radiative forcing of climate change …. By contrast, methane and nitrous oxide are the major contributors to agricultural impacts, as the agricultural sector produces about 50 and 70%, respectively, of the total anthropogenic emissions of these gases.

Nordhaus [30] presents a simple approach for analyzing policies to slow climate change by summarizing the elements of an economic analysis of different approaches to controlling greenhouse warming. The study has focused primarily upon data based on the United States and extrapolated to the rest of the world. The results conclude that an efficient strategy for coping with greenhouse warming must weigh the costs and benefits of different policies. Satterthwaite [32] suggests that the contribution of cities to global anthropogenic greenhouse gas emissions is often overstated. The study further states that worldwide, less than half of all anthropogenic greenhouse gas emissions are generated within city boundaries. However, as greenhouse gas emissions from power stations and industries are assigned to the location of the person or institution consuming them, cities would account for a higher proportion of total emissions. Carlsson-Kanyama [7] examines greenhouse gas emissions and energy consumption during the lifecycle of carrots, tomatoes, potatoes, pork, rice and dry peas consumed in Sweden during the early or mid-1990s. The study shows that emissions, expressed in g CO_2 equivalents, are the highest for pork and rice and the lowest for potatoes, carrots and dry peas. Crop farming is the most important stage for rice and tomatoes while rearing of animals is the most important stage for pork and storage is the most important stage for carrots.

Worrell et al. [40] review the global CO_2 emissions from cement making, including process and energy-related emissions. Further, this study also discusses CO_2 emission mitigation options for the cement industry. The results show that total carbon emissions from cement production in 1994 were 307 million metric tons of carbon (MtC)—160 MtC from process carbon emissions, and 147 MtC from energy use. Overall, the top 10 cement-producing countries in 1994 accounted for 63% of global carbon emissions from cement production. The average intensity of carbon dioxide emissions from total global cement production is 222 kg C/t of cement. According to Bongaarts [3] (p. 299).

> Carbon dioxide (CO_2) and other greenhouse gases produced by natural processes were present in the atmosphere long before the role of humans became significant. By partially blocking the infrared radiation originating from the earth, these gases have kept the globe warmer (by about 32 °C) than would be the case in their absence.

Tyedmers and Parker [35] present the results of a research project which aimed to quantify the fuel use intensity and partial carbon footprint of tuna fisheries in 2009. Results are based on analysis of industry surveys reporting catch and fuel use data, representing approximately 19% of global landings of major tuna species in 2009. Bennetzen et al. [2] present the Kaya–Porter identity which is derived from the Kaya identity, to calculate GHG emissions from agricultural crop production by deconstructing emissions. Using the Kaya–Porter identity, this study performed a case study on Danish crop production and emissions during the period 1992–2008. The results reveal that land-based emissions reduced by 9% and N_2O emissions are 27% lower in 2006–2008 compared to 1992–1994. Emissions have been reduced by 12% from 1992 to 2008, whilst yields per unit area have remained constant. Charlier and Risch [8] construct a simulation model to estimate energy consumption through 2050 and evaluate the impact of environmental policies in France. The results show that while current policies are effective, they are not sufficient to reach the objectives; as the current public policy measures are kept without modifications, energy consumption would still be 91.67 kWh_{pe}/m^2/year in 2050.

According to Girod et al. [18] (p. 1),

> Discussion and analysis on international climate policy often focuses on the rather abstract level of total national and regional greenhouse gas (GHG) emissions. At some point, however, emission reductions need to be translated to consumption level.

Duffy and Crawford [14] estimate activity-related contributions of transport modes to GHG emissions in 10 European countries. The results reveal that typical national food energy-related emissions for walking, cycling, and driving ranged, respectively, from 25.6 to 77.3 gCO_2-eq/pass km, 10.4 to 31.4 gCO_2-eq/pass km and 1.7 to 5.2 gCO_2-eq/pass km; passenger transport was found to result in no food-related emissions above those for a resting individual. Emissions vary between countries depending on the emissions intensities of their energy sectors as well as food prices and average body weights. Soltani et al. [33] analyze energy use and greenhouse gases (GHG) emissions in various wheat production scenarios in north eastern Iran and identify measures to reduce energy use and GHG emissions. The results indicate the key factors which are related to energy use and GHG emissions i.e., seedbed preparation and sowing, and applications of nitrogen fertilizer. The better crop management production scenario required 38% lower nitrogen fertilizer (and 33% lower total fertilizer), consumed 11% less input energy and resulted in 33% more grain yield and output energy compared to the usual

production scenario. It also resulted in 20% less GHG emissions per unit field area and 40% less GHG emissions per ton of grain. According to Krosnick and MacInnis [28] (p. 26).

> Despite efforts by some congressional legislators to pass laws to limit greenhouse gas emissions and reduce the use of fossil fuels, no such laws have yet been adopted. Is this failure to pass new laws attributable to a lack of public desire for such legislation? Data from national surveys support two answers to this question.

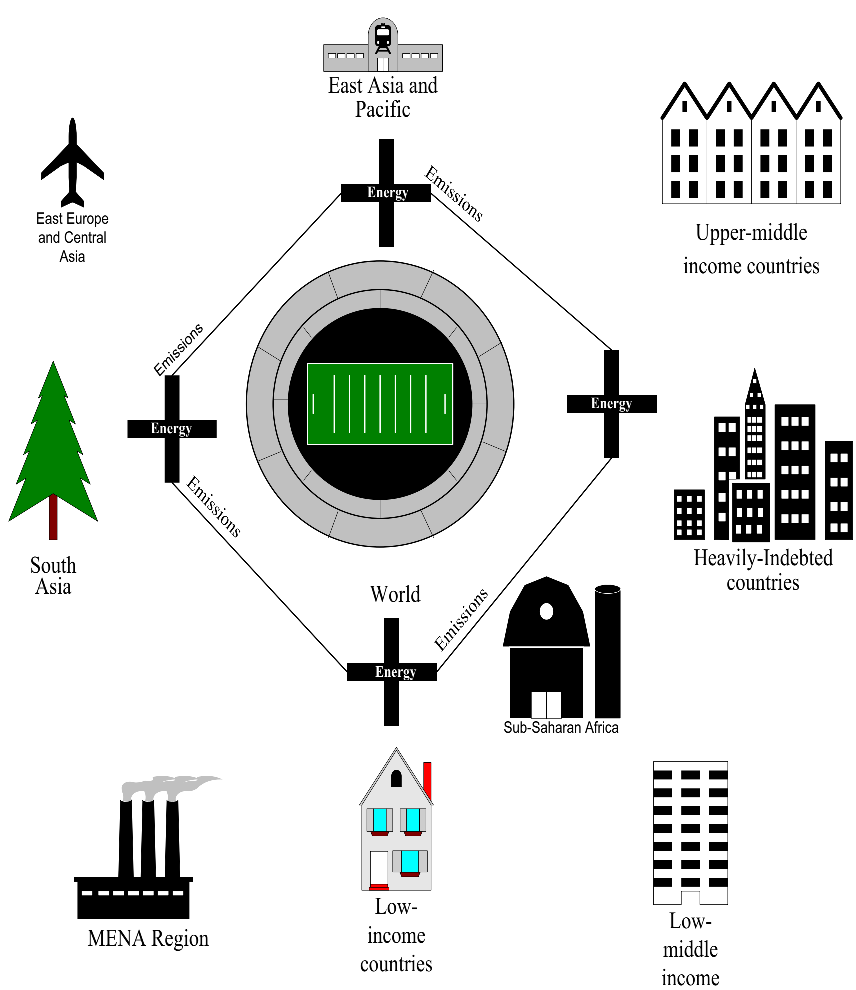
Dietz et al. [12] argued that actions by individuals and households to reduce carbon-based energy consumption have the potential to change the picture of U.S. energy consumption and carbon dioxide emissions in the near term. At the global level, energy policies and programs need to replace outmoded assumptions and they must integrate insights from the energy engineers and social sciences with those from engineering and economics. Hence there is a pressing need to evaluate and analyze the energy–greenhouse gas emissions nexus and to find out the inter-relationship. In the subsequent sections an effort has been made to empirically find out the long-run and casual relationship between energy and greenhouse emissions at the global level.

3. Data source and methodological framework

In this study, we consider aggregate data of the World Bank's regional classification i.e. low-income countries, low middle-income, upper middle-income, and heavily-indebted countries, East Asia and Pacific (EAP), East Europe and Central Asia (ECA), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (SA), Sub-Saharan Africa (SSA) and the world which constitutes balanced panel data over the period of 36 years from 1975 to 2011. A number of variables have been considered to evaluate energy–emission nexus in different regions of the world i.e. energy consumption (kilo ton of oil equivalent), GDP per unit of energy use (constant 2005 PPP $ per kg of oil equivalent); and greenhouse gas emissions (GHG) such as agricultural methane emissions, agricultural nitrous oxide emissions and CO_2 emissions. These variables have been selected due to their vital importance in different regions of the world. All of the data are taken from *World Development Indicators* published by the World Bank [38] and *International Financial Statistics* published by the IMF [22]. Fig. 1 shows the research framework of the study.

The following four equations (Panel A–C) have been used to assess the impact of greenhouse gases on energy consumption in different regions of the world.

$$\text{Panel A}: \quad \text{ENRG}, \; \text{AGRMET}, \; \text{GDPENRG} \tag{1}$$



Source: Self Extract.
Note: In this Figure, all countries have assigned arbitrary sketches according to the profile of their respective country.

Fig. 1. Research framework of the study.

$$\text{Panel B}: \quad \text{ENRG}, \ \text{AGRNIT}, \ \text{GDPENRG} \tag{2}$$

$$\text{Panel C}: \quad \text{ENRG}, \ CO_2, \ \text{GDPENRG} \tag{3}$$

where ENRG represents energy use (kt of oil equivalent); AGRMET represents agricultural methane emissions (thousand metric tons of CO_2 equivalent), AGRNIT represents agricultural nitrous oxide emissions (thousand metric tons of CO_2 equivalent), CO_2 represents carbon dioxide emissions (metric tons per capita), and GDPENRG represents GDP per unit of energy use (constant 2005 PPP $ per kg of oil equivalent).

3.1. Econometric framework of the study

The time series data is often plagued with non-stationarity in levels and hence estimates based on such series usually provide spurious results. Therefore, the first step in any time series analysis is to examine the presence of unit roots in the underlying series so that the problem of spurious relationships among variables can be removed. The second step is to check the order of integration (the number of times data on the variable needs to be differenced to become stationary) of each variable in a data series in the model.

Dickey and Fuller [10,11] devised a procedure to formally test for non-stationarity which does not take into account high order autocorrelation and hence limits the power of the test. The Augmented Dickey–Fuller (ADF) test is used to test the stationarity of the series. The ADF test is a standard unit root test: it analyzes the order of integration of the data series. These statistics are calculated with a constant, and a constant plus time trend, and these tests have a null hypothesis of non-stationarity against an alternative of stationarity.

To test the long run relationship among variables, the Johnson cointegration test can be employed which is a two steps procedure. In the first step, the individual series are tested for a common order of integration. If the series are integrated and are of the same order, it implies co-integration.[1] In the second step, Johansen' cointegration tests are applied on the series of same order of integration i.e. I(1) series which determine the long run relationship between the variables. When the series that are co-integrated are of order 1, a trace test (Johansen's approach) indicates a unique cointegrating vector of order 1 and hence indicates the long run relationship. In the multivariate case, if the I(1) variables are linked by more than one co-integrating vector, the Engle–Granger [15] procedure is not applicable. In general five distinct models can be considered. However the first and the fifth model are not that realistic and they are also implausible in terms of economic theory; therefore, the problem reduces to a choice of one of the three remaining models (Model 2, 3 and 4).

Model 1: no intercept or trend in CE or VAR.
Model 2: intercept (no trend) in CE, no intercept or trend in VAR.
Model 3: intercept in CE and VAR, no trends in CE and VAR.
Model 4: intercept in CE and VAR, linear trend in CE, no trend in VAR.
Model 5: intercept and quadratic trend in the CE intercept and linear trend in VAR.

The test for co-integration used is the likelihood ratio proposed by Johansen and Juselius [27], indicating that the maximum likelihood method is more appropriate in a multivariate system. Therefore, this study has used this method to identify the number of co-integrated vectors in the model. The Johansen and Juselius method has been developed in part by the literature available in the field and reduced rank regression, and the co-integrating vector "r" is defined by Johansen using the fact that at the maximum Eigen-value and in trace test or static, there are "r" or more co-integrating vectors. Johansen [26] and Johansen and Juselius [27] proposed the multivariate co-integration methodology and defined as

$$(\text{ENRG})_t = (\text{GHG}, \ \text{GDPENRG})$$

where GHG represents greenhouse gas emissions, which is a vector of elements. Considering the following autoregressive representation:

$$\text{ENRG}_t = \pi_{\circ} + \sum_{T=1}^{K} \pi_i (\text{ENRG})_{t-1} + \mu_t$$

Johansen's method involves the estimation of the above equation by the maximum likelihood technique, and testing the hypothesis H_o; ($\pi = \Psi\xi$) of "r" co-integrating relationships, where r is the rank or the matrix $\pi(0\angle r\angle P)$, Ψ is the matrix of weights with which the variable enters co-integrating relationships and ξ is the matrix of co-integrating vectors. The null hypothesis of non-cointegration among variables is rejected when the estimated likelihood test statistic $\phi_i\{=-n\sum_{t=r+1}^{p}\ln(1-\hat{\lambda}_i\}$ exceeds its critical value. Given the estimates of the Eigen-value ($\hat{\lambda}_i$),the Eigen-vector (ξ_i) and the weights (Ψ_i), we can find out whether or not the variables in the vector (ENRG) are co-integrated in one or more long-run relationships (GHG, GDPENRG).

This study investigates the influence of world's greenhouse gases on energy consumption from two perspectives. One is to conduct the modified Granger causality and Johansen cointegration tests to explore the influencing directions between greenhouse gases and energy consumption respectively. The other is to compare the influencing magnitude of greenhouse gases on energy consumption, based on the vector error correction model (VECM) and variance decomposition approach.

In order to undertake the modified version of Granger causality for a VAR model with 3 lags (k=2 and $d_{\max}$=1), we study the following system of equations:

$$\begin{bmatrix} \text{ENRG} \\ \text{AGRMET} \\ \text{GDPENRG} \end{bmatrix} = A_0 + A_1 \begin{bmatrix} \text{ENRG} \\ \text{AGRNIT} \\ \text{GDPENRG} \end{bmatrix} + A_2 \begin{bmatrix} \text{ENRG} \\ CO_2 \\ \text{GDPENRG} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix} \tag{5}$$

where A_1 and A_3 are 3×3 matrices of coefficients with A_0 being a 3×1 identity matrix, and ε_t are the disturbance terms with zero mean and constant variance. From Eq. (5) we can test the hypothesis that world's greenhouse gases do not Granger cause energy consumption i.e.,

$$H_0^1 = a_{12}^1 = a_{12}^2 = 0$$

where a_{12}^i are the coefficients of the greenhouse gases in the first equation of the system presented in Eq. (5). Besides, we can test the opposite causality from world's energy consumption to greenhouse gases in the following hypothesis:

$$H_0^2 = a_{21}^1 = a_{21}^2 = 0$$

where a_{21}^i are the coefficients of the energy consumption variable in the second equation of the system presented in Eq. (5). It should be noted that we incorporate the variable GDP per unit of energy use into Eq. (5) to avoid the omitted variable bias when we examine the

[1] If the series are integrated with the mixture of order of integration I(0) and I(1), it implies the bonds testing approach which was proposed by Pesaran et al. [31].

Table 4
Unit root test results by various country groupings (1975–2011).

Country groupings	Order of integration: I(0), I(1) or I(2)				
	Energy consumption (ENRG)	GDP per unit use of energy (GDPENRG)	Agricultural methane emissions (AGRMET)	Agricultural nitrous oxide emissions (AGRNIT)	Carbon dioxide emissions (CO_2)
Low-income countries	I(1)*	I(1)*	I(0)**	I(1)*	I(1)*
Low middle-income	I(1)*	I(0)**	I(1)*	I(2)**	I(1)*
Upper middle-income	I(0)**	I(1)**	I(0)*	I(1)*	I(2)**
Heavily-indebted countries	I(1)*	I(0)**	I(2)*	I(1)*	I(0)**
East Asia and Pacific (EAP)	I(2)**	I(1)*	I(1)*	I(1)*	I(0)**
East Europe and Central Asia (ECA)	I(0)**	I(1)*	I(0)**	I(1)*	I(2)**
Latin America and Caribbean (LAC)	I(1)*	I(0)***	I(2)**	I(0)**	I(1)*
Middle East and North Africa (MENA)	I(1)*	I(1)*	I(0)*	I(1)*	I(1)*
South Asia (SA)	I(1)*	I(1)*	I(0)**	I(0)***	I(1)**
Sub-Saharan Africa (SSA)	I(1)*	I(1)*	I(1)*	I(1)*	I(1)*
All countries	I(1)*	I(0)**	I(0)*	I(2)**	I(1)*
I(1)/Total countries	8/11	7/11	3/11	7/11	7/11
Percentages	72.7%	63.6%	27.2%	63.6%	63.6%

Note: The null hypothesis is that the series is non-stationary, or contains a unit root. The rejection of the null hypothesis is based on MacKinnon [29] critical values i.e., at constant, −3.639, −2.951 and −2.614 are significant at *: 1%, **: 5% and ***: 10% level respectively, while at constant and trend, *: −4.252, **: −3.548 and ***: −3.207 are significant at 1%, 5% and 10% level respectively. The lag lengths are selected based on SIC criteria; this ranges from lag zero to lag five.

Granger causality bias when we examine the Granger causality between greenhouse gas emissions and energy consumption.

4. Results and discussions

4.1. Cointegration among greenhouse gases and energy consumption

The present study performs the Augmented Dickey–Fuller (ADF) unit root tests for variables with regard to their stationary properties. The detailed results are shown in Table 4.

The results reveal that most of the variables are non-stationary at their level in different regions of the world, but, stationary at their first differences i.e. I(1) variables. A few of the variables show stationary series at a level which shows I(0) variables i.e. order of integration zero while some variables contain unit root at second lag i.e. I(2) variables. 72.7% of energy consumption data is non-stationary at a level; however, after taking first difference it becomes stationary. The order of integration one i.e. I(1) data for GDP per unit use of energy, agricultural nitrous oxide emission and carbon dioxide emissions, each contributed 63.6% in all 11 regions of the world. Only low–middle income countries, East Asia and Pacific and Sub-Saharan African region that contribute only 27.2% of agricultural methane emissions have order of integration one.

After that, we take energy consumption (ENRG) as the dependent variable and each greenhouse gases and GDP per unit use of energy (GDPENRG) together as the independent variable, and then the cointegration is tested according to Johansen (1988). From the results in Table 5, we find that all greenhouse gas emissions have at least one cointegration relationship with energy consumption at 5% level. Low income countries, upper middle income, heavily-indebted countries, East Asia and Pacific (EAP), and South Asia have a long-run cointegration in all Panels A–C, while low middle income ones have a cointegration in Panel A and Panel C only, East Europe and Central Asia (ECA) in Panel C only, Latin America and Caribbean (LAC) in Panels A and B, MENA and sub-Saharan Africa have Panel A only and finally, all countries have a cointegration in Panels B and C. Therefore, we may say that, greenhouse gases have significant long-term equilibrium with energy consumption all over the world.

4.2. Causality among greenhouse gases and energy consumption

Subsequently, we conduct the modified Granger causality tests by Toda and Yamamoto [34] for greenhouse gas emissions and energy consumption. The variable GDP per unit use of energy (GDPENRG) is incorporated as an explanatory variable to avoid the omitted variable bias. Results are shown in Table 6.

The results reveal that "energy consumption (ENRG) does not Granger cause agriculture methane gas emissions (AGRMET)" and "agriculture methane gas emissions (AGRMET) do not Granger cause energy consumption (ENRG)" are accepted in heavily-indebted countries; East Europe and Central Asia; Latin America and Caribbean and Sub-Saharan Asian region. The results suggest that there is causality independence between energy consumption and agriculture methane gas emissions in the world. The results indicate causality between energy and carbon dioxide emissions in Low Middle income; East Asia and Pacific; East Europe and Central Asia; MENA region; sub-Saharan Africa and all countries. The results for low income countries; Upper middle income; Latin American and Caribbean; MENA and South Asian regions have no causality between energy consumption and agricultural nitrous oxide emissions. The results further enlighten the unidirectional causality running towards only energy consumption to agricultural methane gas emissions in low income, middle income, upper middle income, East Asia and Pacific, MENA region, South Asia and all countries. Energy Granger causes agriculture nitrous oxide emissions in low middle income, heavily indebted countries, East Asia and Pacific, East Europe and Central Asia and sub-Saharan Africa. Similarly, energy Granger causes carbon dioxide emissions in low income countries, upper middle income, heavily indebted countries, Latin America and Caribbean and South Asia. These results confirm the "energy led emissions" hypothesis; in emissions in the form of agricultural methane gas emissions, agricultural nitrous oxide emissions or carbon dioxide emissions; all these gases have been emitted due to usage of energy consumption in the selected regions of the world. Governments should rely heavily on energy efficiency measures as a means to cut greenhouse gases ([25]). The results reflect that greenhouse gases are closely associated with energy consumption and GDP per unit use of energy in the world. In reality, the agricultural gases are

Table 5
Results of Johansen cointegration tests by various country groupings.

Country groupings	**Hypothesized number of cointegration equations**				
	Panel A series: ENRG, AGRMET, GDPENRG	**Panel B series: ENRG, AGRNIT, GDPENRG**	**Panel C series: ENRG, CO_2, GDPENRG**	**5% Critical values**	**Decision**
Low-income countries	None*	None*	None*	29.797	Cointegration
	At most 1*	At most 1	At most 1*	15.494	
	At most 2	At most 2	At most 2*	3.841	
Low middle-income	None*	None	None*	29.797	Cointegration in Panel A and Panel C series
	At most 1	At most 1	At most 1*	15.494	
	At most 2	At most 2	At most 2	3.841	
Upper middle-income	None*	None*	None*	29.797	Cointegration series
	At most 1*	At most 1*	At most 1	15.494	
	At most 2	At most 2	At most 2	3.841	
Heavily-indebted countries	None*	None*	None*	29.797	Cointegration series
	At most 1*	At most 1*	At most 1*	15.494	
	At most 2*	At most 2	At most 2*	3.841	
East Asia and Pacific (EAP)	None*	None*	None*	29.797	Cointegration series
	At most 1	At most 1	At most 1	15.494	
	At most 2	At most 2	At most 2	3.841	
East Europe and Central Asia (ECA)	None	None	None*	29.797	Cointegration in Panel C series
	At most 1	At most 1	At most 1*	15.494	
	At most 2	At most 2	At most 2	3.841	
Latin America and Caribbean (LAC)	None*	None*	None	29.797	Cointegration in Panel A and Panel B series
	At most 1*	At most 1	At most 1	15.494	
	At most 2*	At most 2	At most 2	3.841	
Middle East and North Africa (MENA)	None*	None	None	29.797	Cointegration in Panel A series
	At most 1	At most 1	At most 1	15.494	
	At most 2	At most 2	At most 2	3.841	
South Asia (SA)	None*	None*	None*	29.797	Cointegration series
	At most 1*	At most 1	At most 1*	15.494	
	At most 2	At most 2	At most 2	3.841	
Sub-Saharan Africa (SSA)	None*	None	None	29.797	Cointegration in Panel A series
	At most 1	At most 1	At most 1	15.494	
	At most 2	At most 2	At most 2	3.841	
All countries	None	None*	None*	29.797	Cointegration in Panel B and Panel C series
	At most 1	At most 1*	At most 1*	15.494	
	At most 2	At most 2*	At most 2	3.841	

Note: Dependent variable in each Johansen cointegration test is ENRG.

* Denotes rejection of the hypothesis at the 5% level.

Table 6
Causality test results among greenhouse gases and energy consumption by various country groupings.

Country groupings	**Null hypothesis: ENRG do not Grange cause the changes in GHG emissions, GHG emissions does not Granger cause the changes in ENRG**			
	ENRG→AGRMET	**ENRG→AGRNIT**	**ENRG→CO_2**	Decision
Low-income countries	✓		✓	No causality between ENRG and AGRNIT
Low middle-income	✓	✓		No causality between ENRG and CO2
Upper middle-income	✓		✓	No causality between ENRG and AGRNIT
Heavily-indebted countries		✓	✓	No causality between ENRG and AGRMET
East Asia and Pacific (EAP)	✓	✓		No causality between ENRG and CO_2
East Europe and Central Asia (ECA)		✓		No causality between ENRG and AGRMET; ENRG and CO_2
Latin America and Caribbean (LAC)			✓	No causality between ENRG and AGRMET; ENRG and AGRNIT
Middle East and North Africa (MENA)	✓			No causality between ENRG and AGRNIT; ENRG and CO_2
South Asia (SA)	✓		✓	No causality between ENRG and AGRNIT
Sub-Saharan Africa (SSA)		✓		No causality between ENRG and AGRMET; ENRG and CO_2
All countries	✓			No causality between ENRG and AGRNIT; ENRG and CO_2

Note: The modified Granger causality test approach used in the table is provided by Toda and Yamamoto [34]. The causality tests between greenhouse gases and energy consumption are based on the significance of chi-square statistics for Wald tests of VAR models.

closely related to energy consumption in different regions of the world.

4.3. Johansen cointegration test between all greenhouse gases and energy consumption followed by variance decomposition analysis

In order to compare the contribution extents of various greenhouse gas emissions, the variance decomposition approach is adopted over the sample period. First, we take the energy consumption as the dependent variable, while greenhouse gases coupled with GDP per unit use of energy as the independent variable, and conduct the Johansen cointegration test among these variables over a period of 36 years. The results indicate that there exists statistically significant cointegration among greenhouse gases and energy consumption in the world. Next, we apply the variance decomposition approach based on the vector error

Table 7
Results of variance decomposition analysis by various country groupings.

Country groupings	Variance decomposition analysis (%) between ENRG and other factors				
	GDP per unit use of energy (GDPENRG)	Agricultural methane emissions (AGRMET)	Agricultural nitrous oxide emissions (AGRNIT)	Carbon dioxide emissions (CO_2)	Highest contributing factor influence to changes in ENRG
Low-income countries	36.8%	15.2%	8.1%	4.5%	GDP per unit use of energy
Low middle-income	1.08%	19.25	33.4%	11.0%	Agricultural nitrous oxide emissions
Upper middle-income	3.6%	9.15	17.4%	41.4%	Carbon dioxide emissions
Heavily-indebted countries	41.8%	8.2%	11.25	27.4%	GDP per unit use of energy
East Asia and Pacific (EAP)	17.2%	2.0%	17.2%	31.8%	Carbon dioxide emissions
East Europe and Central Asia (ECA)	1.9%	11.8%	3.2%	48.8%	Carbon dioxide emissions
Latin America and Caribbean (LAC)	14.2	9.85	0.89%	56.8%	Carbon dioxide emissions
Middle East and North Africa (MENA)	2.8%	19.5%	3.8%	34.8%	Carbon dioxide emissions
South Asia (SA)	1.0%	4.5%	8.95	47.9%	Carbon dioxide emissions
Sub-Saharan Africa (SSA)	15.2%	3.9%	16.8%	3.8%	Agricultural nitrous oxide emissions
All countries	3.6%	4.1%	11.9%	19.8%	Carbon dioxide emissions

correction model (VECM) to explore the influence of greenhouse gases on energy consumption, and compare their contribution differences. The results of variance decomposition analysis are shown in Table 7.

The results show that, among all greenhouse gases, carbon dioxide emissions exert the largest influence, whose steady contribution level on energy is 41.4% in upper middle income, 31.8% in EAP region, 48.8% in ECA region; 56.8% in LAC region, 34.8% in MENA region, 47.9% in SA region and at last, in the world, its contribution is 19.8% on average. This is followed by the influence of agricultural nitrous oxide emissions (AGRNIT) in the form of thousand metric tons of CO_2 equivalent with steady contribution level of 33.4% in low-middle income countries and 16.8% in sub-Saharan African region. Finally, GDP per unit of energy use exerts 36.8% in low income countries and 41.8% in heavily indebted countries of the world. The overall results indicate that below-cost energy efficiency is critical for economic growth and should thus be aggressively pursued by governments and firms to reduce energy consumption or greenhouse gas emissions.

Today, it is widely accepted that human activities are contributing to climate change. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) estimated that between 1970 and 2004, global greenhouse gas emissions due to human activities rose by 70% [24]. The following results have been emerged from this exercise i.e.

- Given the environmental policy development and high energy market volatilities, reducing energy use and greenhouse gas emissions could improve the profitability of energy-intensive agricultural firms and reduce its exposure to regulatory and market risks [17].
- Emissions of greenhouse gases have a global impact, unlike some other forms of pollution. Whether they are emitted in Asia, Africa, Europe, or the Americas, they rapidly disperse evenly across the globe. This is one reason why efforts to address climate change have been through international collaboration and agreement [36].
- Given this close relationship between energy use and GHG emissions, near-term energy policy choices have significant future implications for climate change. Climate-friendly energy policies fall into one of three general categories: (i) reduce GHG emissions now; (ii) promote technology advancement or infrastructure development that will reduce the costs of achieving GHG emissions reductions in the future; and (iii) minimize the amount of new capital investment in assets that would be substantially devalued (or "stranded") if a GHG program were to be implemented [5].

5. Conclusion

This study examines the relationship among energy consumption, economic growth and greenhouse gas emissions in the context of 10 different regions of the world over a period of 1975–2011. The results find that energy consumption is closely connected with greenhouse gas emissions, and carbon dioxide emissions exert the largest influence on changes in energy consumption in different regions of the world. In terms of the causality methodology, this study investigates two main hypothesis i.e. firstly, the energy-led growth hypothesis and the growth-led energy hypothesis, and secondly, energy-led emissions hypothesis and emission-led energy hypothesis. Within this framework, this study gives rise to four alternative cases. In particular, causality may result in (i) unidirectional causality from energy consumption to economic growth (and energy consumption to greenhouse gas emissions), (ii) unidirectional causality from economic growth to energy consumption (and greenhouse gas emissions to energy consumption), (iii) bi-directional causality from energy consumption to economic growth (and energy consumption to emissions), and (iv) no causality between the variables (the neutrality hypothesis). The results indicate that energy consumption Granger causes greenhouse gas emissions and energy consumption Granger causes GDP per unit energy use, which confirms the energy led emissions and energy led growth hypotheses globally but not vice versa. The results imply that energy conservation policies aiming at protecting the environment are expected to deteriorate the current stage of economic growth [1].

Efforts to protect local environments can also contribute to carbon mitigation. Improving local air quality often results in lesser GHG emissions (exceptions include sulfur scrubbing on power plants). The switching from high- to low-carbon fuels and promoting energy efficiency result in better air quality and lower carbon emissions. Reducing deforestation protects water supplies and agricultural land while increasing carbon sequestration [6].

The overarching conclusion of this study is that reducing GHG emissions and energy consumption would be an enormous challenge that requires stronger policy initiatives than are currently being discussed by policy makers.

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